

A PRECAST CONCRETE BUILDING SYSTEM
FOR AN URBAN UNIVERSITY

BY GARY J. CROWELL
BACHELOR OF ARCHITECTURE WITH DISTINCTION
UNIVERSITY OF MINNESOTA 1966

SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ARCHITECTURE AT THE
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SIGNATURE OF AUTHOR

DEPARTMENT OF ARCHITECTURE, JUNE 17, 1968

CERTIFIED BY

THESIS SUPERVISOR

ACCEPTED BY

CHAIRMAN DEPARTMENTAL COMMITTEE ON
GRADUATE STUDENTS

Rotch



ABSTRACT

A PRECAST CONCRETE BUILDING SYSTEM
FOR AN URBAN UNIVERSITY

BY GARY J. CROWELL

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE
ON JUNE 17, 1968 IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER
OF ARCHITECTURE.

THE PURPOSE OF THIS THESIS WAS TO DEVELOP
AN INTEGRATED BUILDING SYSTEM FOR AN URBAN
UNIVERSITY BASED ON ADVANCES IN PRESENT-
DAY TECHNOLOGY. THE BUILDING SYSTEM WAS
CONCEIVED AS A TOTAL SYSTEM OF LIFE, SPACE,
GROWTH, CHANGE, ENVIRONMENTAL CONTROL,
CIRCULATION, STRUCTURE AND MECHANICAL
SERVICES.

THE BUILDING SYSTEM DEVELOPED CONSISTS OF
A TWO-WAY PRECAST CONCRETE FLOOR SYSTEM
SUPPORTED ON FOUR COLUMNS 48' ON CENTERS.
PRECAST UNITS ARE ASSEMBLED IN A MANNER
WHICH PROVIDES A 6' X 6' PLANNING MODULE.
A 3'8" STRUCTURAL DEPTH ALLOWS FOR PRIMARY
HORIZONTAL MECHANICAL SERVICES RUNNING
DIAGONALLY FROM VERTICAL RISERS AT THE
COLUMNS. SECONDARY SERVICES RUN PARALLEL
WITH THE PLANNING GRID. VARIOUS CORE
ELEMENTS ARE PROVIDED AT VARIOUS FRE-
QUENCIES DEPENDING ON THE BUILDING
OCCUPANCIES.

THESIS SUPERVISOR: EDUARDO CATALANO
TITLE: PROFESSOR OF ARCHITECTURE

SUBMISSION LETTER

CAMBRIDGE, MASSACHUSETTS
JUNE 1968

DEAN LAWRENCE BERNHART ANDERSON
SCHOOL OF ARCHITECTURE AND PLANNING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
77 MASSACHUSETTS AVENUE
CAMBRIDGE, MASSACHUSETTS 02139

DEAR DEAN ANDERSON:

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ARCHITECTURE,
I HEREBY SUBMIT THIS THESIS ENTITLED "A
PRECAST CONCRETE BUILDING SYSTEM FOR AN
URBAN UNIVERSITY".

RESPECTFULLY,

GARY J. CROWELL

ACKNOWLEDGMENT

THE AUTHOR GRATEFULLY ACKNOWLEDGES THE
INVALUABLE ADVICE AND ASSISTANCE OF THE
FOLLOWING PEOPLE IN THE DEVELOPMENT OF
THIS THESIS:

EDUARDO CATALANO
PROFESSOR OF ARCHITECTURE

YUSING Y. JUNG
VISITING PROFESSOR OF ARCHITECTURE

WACLAW ZALEWSKI
PROFESSOR OF STRUCTURES

ROBERT B. NEWMAN
ASSOCIATE PROFESSOR OF ARCHITECTURE

CHARLES CRAWLEY
MECHANICAL ENGINEER

AND WISHES TO THANK HIS WIFE JUDITH FOR
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TABLE OF CONTENTS

TITLE PAGE

ABSTRACT

SUBMISSION LETTER

ACKNOWLEDGMENT

TABLE OF CONTENTS

INTRODUCTION 1

SYSTEMS DEFINED 3

PREFABRICATION 7

DESIGN CRITERIA 10

PRELIMINARY PROPOSAL 18

FINAL PROPOSAL 27

CONCLUSION 38

APPENDIX A - CALCULATIONS

APPENDIX B - COMPUTER SUPPLEMENT

FOOTNOTES

BIBLIOGRAPHY

PHOTOGRAPHS OF PRELIMINARY PROPOSAL

PHOTOGRAPHS OF FINAL PROPOSAL

INTRODUCTION

DURING THE NEXT TEN YEARS OUR PRESENT POPULATION OF 200 MILLION WILL INCREASE TO 231 MILLION AND, WITH THIS, THE MOVEMENT OF POPULATION TO THE URBAN AREAS WILL CONTINUE TO INCREASE. THESE TRENDS POINT TOWARD A VIRTUAL EXPLOSION IN FUTURE NEEDS AND SUBSEQUENT DEMANDS ON THE ARCHITECT AND BUILDING INDUSTRY.

THE CONTEMPORARY ARCHITECT, UNDER THE INFLUENCE OF TRADITION, IS TRAINED PRIMARILY AS AN ARTIST AND HIS FAMILIARITY WITH THE BASIC TOOLS NECESSARY FOR AN UNDERSTANDING OF MODERN TECHNOLOGY IS OFTEN LIMITED. WHILE SOCIETY DEMANDS AN UNPRECEDENTED VOLUME OF BUILDING, WE ARE STILL DESIGNING INDIVIDUAL BUILDINGS AS INDIVIDUAL EXPRESSIONS FOR SPECIALIZED FUNCTIONS AND ASSEMBLING THEM FROM UNRELATED COMPONENTS. IN ADDITION, THE BUILDING INDUSTRY, WHICH FORMS THE LARGEST SINGLE ELEMENT IN OUR ECONOMY, LAGS FAR BEHIND OTHER INDUSTRIES IN THE USE OF MASS-PRODUCED STANDARDIZED PARTS.

WITH THE DEMAND FOR INCREASED BUILDING VOLUME, THERE IS ALSO A NEED FOR BUILDINGS WHICH PROVIDE FOR MORE FLEXIBILITY. FUNCTIONAL REQUIREMENTS ARE CONSTANTLY CHANGING AND BECOMING SO COMPLEX THAT THE ABILITY OF BUILDINGS TO SERVE OFTEN BECOMES OBSOLETE LONG BEFORE THE BUILDING STRUCTURE.

WE MUST THEREFORE SEARCH FOR NEW METHODS OF CONSTRUCTION BASED ON SCIENTIFIC AND TECHNICAL ADVANCEMENTS WHICH WILL ALLOW FOR MAXIMUM FLEXIBILITY IN INITIAL USE AND SYSTEMATIC GROWTH AND CHANGE IN FUTURE USE.

SYSTEMS DEFINED

THE WORD "SYSTEM" HAS MANY MEANINGS AND MUCH CONFUSION EXISTS TODAY AS TO ITS PROPER USE. TO HELP CLARIFY THE MEANING AND GIVE DIRECTION TO THIS PROJECT, THE FOLLOWING MATERIAL PRESENTS SOME OF THE LATEST VIEWS ON SYSTEMS IN GENERAL AND BUILDING SYSTEMS IN PARTICULAR.

CHRISTOPHER ALEXANDER, IN THE FIRST ISSUE OF A NEW PUBLICATION CALLED SYSTEMAT, POINTS OUT TWO CENTRAL MEANINGS OF THE WORD "SYSTEM": (1) THE IDEA OF A SYSTEM AS A WHOLE AND (2) THE IDEA OF A GENERATING SYSTEM.

ALEXANDER SAYS, "THESE TWO VIEWS THOUGH SUPERFICIALLY SIMILAR ARE LOGICALLY QUITE DIFFERENT. IN THE FIRST CASE THE WORD SYSTEM REFERS TO A PARTICULAR 'HOLISTIC' VIEW OF A SINGLE THING. IN THE SECOND CASE THE WORD SYSTEM DOES NOT REFER TO A SINGLE THING AT ALL, BUT TO A KIT OF PARTS AND COMBINATORY RULES CAPABLE OF GENERATING MANY THINGS."¹

HE FURTHER STATES, "ALMOST EVERY SYSTEM AS A WHOLE IS GENERATED BY A GENERATING SYSTEM.

IF WE WISH TO MAKE THINGS WHICH FUNCTION AS WHOLES WE SHALL HAVE TO INVENT GENERATING SYSTEMS TO CREATE THEM."²

ACCORDING TO ALEXANDER THEN, A BUILDING SYSTEM IS A GENERATING SYSTEM. IT PROVIDES A KIT OF PARTS WHICH MUST BE PUT TOGETHER ACCORDING TO CERTAIN RULES.

IN A VOLUME RECENTLY PUBLISHED BY THE M.I.T. DEPARTMENT OF ARCHITECTURE CALLED PLASTICS IN ARCHITECTURE, WILLIAM J. LE MESSURIER ELABORATES ON THE IDEA OF BUILDING SYSTEMS AS GENERATING SYSTEMS. LE MESSURIER SAYS, "SYSTEMS DO NOT JUST APPEAR OUT OF NOWHERE; THERE ARE SUCH THINGS AS GENERATING SYSTEMS. BY TAKING A LOOK AT THE DIFFERENT KINDS OF GENERATING SYSTEMS IN RELATION TO BUILDING SYSTEMS, WE MAY SEE SOME DIFFERENCES."³ LE MESSURIER GOES ON TO SITE THREE GENERATORS OF BUILDING SYSTEMS: (1) EVOLUTION, (2) INDIVIDUALS AND (3) GROUPS OF PEOPLE OR SYSTEMS ANALYSTS. HE ALSO LISTS SEVERAL ITEMS WHICH ARE COMMON TO ANY BUILDING SYSTEM. THESE ITEMS INCLUDE: (1) DIMENSIONAL

STANDARDIZATION, (2) RELATION TO LOCAL ECONOMY AND (3) FLEXIBILITY OR ADAPTABILITY TO A WIDE VARIETY OF PLANS. IN ADDITION IT MUST INCLUDE SOME KIND OF MECHANICAL SYSTEM, ELECTRICAL SYSTEM, AND AN UNDERSTANDING OF THE RELATIONSHIP BETWEEN THESE SUB-SYSTEMS AND THE STRUCTURAL SYSTEM.

FROM THIS ARTICLE THE CONCLUSION CAN BE DRAWN THAT EVOLUTION PROBABLY IS THE BEST GENERATOR OF SYSTEMS AND THAT THE WOOD FRAME HOUSE IS ONE OF THE BEST EXAMPLES OF EVOLUTIONARY BUILDING SYSTEMS. IT IS POINTED OUT THAT THERE IS A NEED FOR HOUSING, MATERIALS ARE AVAILABLE, LAWS OF SUPPLY AND DEMAND ARE AT WORK AND, FROM THIS, OVER A PERIOD OF TIME, BUILDING SYSTEMS EVOLVE.

THE SECOND GENERATOR OF BUILDING SYSTEMS, THE INDIVIDUAL, IS PROBABLY THE MOST FAMILIAR. LE MESSURIER POINTS OUT THAT EVERY ARCHITECT, TO SOME DEGREE, DEVELOPS A NEW SYSTEM FOR EACH BUILDING AND THAT THE PROBLEM WITH THE INDIVIDUAL TRYING TO GENERATE BUILDING SYSTEMS IS THAT HE TRIES TO FIND A SINGLE PATTERN TO THE PROBLEM.

HE TURNS TOWARD THOSE THINGS WHICH WILL
LEAD TO VISIBLE FORM RATHER THAN THOSE
THINGS WHICH LEAD TO SOME OTHER KIND OF
RESULT.

THE THIRD GENERATOR OF BUILDING SYSTEMS,
GROUPS OF PEOPLE OR SYSTEMS ANALYSTS, ARE
BORROWING TECHNIQUES FROM OTHER PARTS OF
INDUSTRIAL LIFE. THEY ARE DELIBERATELY
GENERATING SYSTEMS AND THINKING ABOUT
SYSTEMS FOR GENERATING SYSTEMS. THE BEST
KNOWN EXAMPLE IS A TEAM HEADED BY EZRA
EHRENKRANTZ. THIS TEAM DEVELOPED THE
S.C.S.D. BUILDING SYSTEM IN CALIFORNIA.
THE OBJECT OF THIS PROJECT WAS TO EXPERI-
MENT WITH NEW DESIGNS IN CONSTRUCTION PRO-
CEDURES FOR THE BUILDING OF HIGH SCHOOLS.
THE BASIC IDEA WAS TO PROVIDE A BIG ENOUGH
MARKET TO ENABLE MANUFACTURERS TO DESIGN
AND PRODUCE A SERIES OF BUILDING SUB-SYSTEMS.
THESE SUB-SYSTEMS ARE AS FOLLOWS: 4

- STRUCTURE
- HEATING, VENTILATING AND COOLING
- LIGHTING, CEILING AND AIR DIFFUSERS
- INTERIOR PARTITIONS
- CASEWORK
- STUDENT LOCKERS

PREFABRICATION

A STUDY ON "THE STATE OF THE ART OF PREFABRICATION" IN THE CONSTRUCTION INDUSTRY WAS RECENTLY UNDERTAKEN BY THE BATTELLE MEMORIAL INSTITUTE FOR THE BUILDING AND CONSTRUCTION TRADES DEPARTMENT OF THE A.F.L.-C.I.O. THIS STUDY WAS CONCERNED PRIMARILY WITH ESTIMATING THE AMOUNT AND TYPES OF CONSTRUCTION WORK THAT MAY BE TRANSFERRED FROM THE JOB SITE TO THE FACTORY AND WITH DETERMINING THE CHANGES IN CHARACTER OF WORK AS A RESULT OF THE TREND TOWARD PREFABRICATION. THE FINDINGS OF THIS STUDY ARE SUMMARIZED BELOW.

PREFABRICATION IN EUROPE

PREFABRICATION AND INDUSTRIALIZED BUILDING METHODS ARE RESPONSIBLE FOR ABOUT 25% OF ALL CONSTRUCTION PUT INTO PLACE IN EUROPE. TO ACHIEVE THIS THE EUROPEANS HAVE DEVELOPED BUILDING SYSTEMS WHICH LEND THEMSELVES TO MECHANIZATION AND AUTOMATION. A FREQUENTLY USED DEFINITION FOR A BUILDING SYSTEM IN EUROPE IS "THE APPLICATION OF MODERN TECHNIQUES TO COORDINATE DESIGN, MANUFACTURING, SITE OPERATIONS, AND OVERALL FINANCIAL AND MANAGERIAL ADMINISTRATION INTO A DISCIPLINED METHOD OF BUILDING". THESE SYSTEMS MAY BE EITHER "OPEN" OR CLOSED AND ARE INITIATED BY ANY OF FOUR TYPES OF ORGANIZATIONS: (1) CONTRACTORS, (2) ENGINEERS, (3) CLIENTS AND (4) MANUFACTURERS.

THE ADVANTAGES OF THESE SYSTEMS ARE THAT THEY REDUCE SKILL CONTENT, ACCELERATE THE ERECTION PROCEDURE, AND CENTRALIZE THE CONTROL AND RESPONSIBILITY FOR THE CONSTRUCTION PROCESS.

THE POSSIBILITY OF SUCCESS FOR THE EUROPEAN SPONSORED BUILDING SYSTEM IN THE UNITED STATES BEFORE 1975 APPEARS QUITE LOW BECAUSE OF A NUMBER OF PROBLEMS SUCH AS BUILDING CODES, BIDDING PROCEDURES AND ROYALTY FEES.⁵

PREFABRICATION IN THE UNITED STATES

MOST OF THE BUILDINGS IN THE UNITED STATES THAT ARE BEING ASSEMBLED ON SITE FROM FACTORY MADE COMPONENTS ARE IN THE LOW RISE CATEGORY. THE END RESULT IS THE RAPID ERECTION OF THE BASIC SHELL WHICH ACCOUNTS FOR ONLY ABOUT 30% OF THE TOTAL COST OF THE STRUCTURE.

ACCORDING TO THE BATTELLE INSTITUTE, PREFABRICATION IN THE U.S. WILL DEFINITELY GROW BUT ITS GROWTH WILL BE EVOLUTIONARY RATHER THAN REVOLUTIONARY. BY 1975 A FEW U.S. FIRMS WILL PROBABLY INITIATE SOME SUCCESSFUL HIGH RISE BUILDING SYSTEMS THAT WILL REPRESENT MODIFICATIONS OF EUROPEAN SYSTEMS. THERE WILL BE MORE OPPORTUNITY FOR ADVANCES IN PREFABRICATION IN THE NON-RESIDENTIAL SEGMENTS OF THE INDUSTRY THAN IN ANY OTHER SEGMENTS. THE MAJOR CHANGES IN CONSTRUCTION METHODS WILL BE: (1) THE INCREASED USE OF LARGE INTERIOR SUB-SYSTEMS THAT OFFER SUFFICIENT FLEXIBILITY TO SATISFY A WIDE VARIETY OF INDIVIDUAL NEEDS; (2) THE INCREASED USE OF LIFT-SLAB AND TILT-UP CONSTRUCTION TECHNIQUES AS WELL AS CURTAIN WALL SYSTEMS AND PREASSEMBLED BRIDGE SECTIONS. CONSTRUCTION EQUIPMENT WILL CONTINUE TO BECOME LARGER IN AN ATTEMPT TO OFF-SET RISING LABOR COSTS.

NO RADICAL CHANGES IN MATERIAL OR PRODUCTS ARE ANTICIPATED IN THE NEXT TEN YEARS. ALTHOUGH A NUMBER OF COMPANIES ARE CURRENTLY CONDUCTING EXTENSIVE RESEARCH AND DEVELOPMENT PROGRAMS AND DIRECTED TOWARD NEW MARKETS AND NEW APPLICATIONS FOR EXISTING MATERIALS.

THE PRINCIPLE CONSTRAINTS TO THE GROWTH OF PREFABRICATION BETWEEN NOW AND 1975 WILL BE BUILDING CODES, ZONING REGULATIONS, ARCHITECTS, UNIONS, TRANSPORTATION, CAPITAL REQUIREMENTS TRADITION, AND THE BASIC STRUCTURE OF THE CONSTRUCTION INDUSTRY.⁶

DESIGN CRITERIA

BASED ON INDIVIDUAL RESEARCH AND DATA ESTABLISHED BY PAST STUDIES ON BUILDING SYSTEMS AT M.I.T., THE FOLLOWING LIST OF ITEMS AND THEIR REQUIREMENTS ARE GIVEN AS THE DESIGN CRITERIA USED IN THE DEVELOPMENT OF THE BUILDING SYSTEM DESIGNED.

SYSTEM NETWORK

THE BUILDING SYSTEM SHOULD BE BASED ON A LIMITLESS "BUILDING FOOTPRINT" COMPOSED OF BASIC STRUCTURAL, MECHANICAL AND CIRCULATORY ELEMENTS FROM WHICH VARIOUS BUILDING FORMS WITH DIFFERENT SPATIAL QUALITIES AND CHARACTER CAN BE DEFINED.

GROWTH AND CHANGE

THE BUILDING SYSTEM SHOULD PROVIDE FOR MAXIMUM FLEXIBILITY IN INITIAL USE AND ADAPTABILITY TO CHANGE IN FUTURE USE.

VITAL STRUCTURAL AND MECHANICAL COMPONENTS (COLUMNS, GIRDERS, MAIN MECHANICAL SERVICE BRANCHES) SHOULD REMAIN PERMANENT ELEMENTS OF THE SYSTEM WITH SECONDARY COMPONENTS (BEAMS, JOISTS, SECONDARY MECHANICAL

SERVICE BRANCHES) BECOMING TEMPORARY
ELEMENTS.

A SYSTEM OF GROWTH SHOULD BE PROVIDED
UTILIZING SELF-SUFFICIENT UNITS OF
STRUCTURE, MECHANICAL SERVICE AND CIR-
CULATION.

SPACE REQUIREMENTS

AS A GUIDE FOR ESTABLISHING A PLANNING
MODULE, BAY SIZE AND MECHANICAL SERVICE
REQUIREMENTS, THE FOLLOWING LIST OF SPACE
TYPES AND AREA REQUIREMENTS ARE PROVIDED:

ADMINISTRATION

GENERAL OFFICES	100-400 FT ²
FACULTY OFFICES	100 FT ²

COMMONS

MEETING ROOMS	700 FT ²
DINING	4,000 FT ²

LIBRARY

CONFERENCE ROOMS	400 FT ²
READING ROOMS	1,000 FT ²

SCIENCE AND TECHNOLOGY

TWO-MAN RESEARCH AND GRADUATE LABORATORIES	400 FT ²
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TWO 24-MAN UNDERGRADUATE LABORATORIES (1,200 SQ. FT. EACH) WITH BALANCE ROOMS (200 SQ. FT.) AND STORAGE ROOM (400 SQ. FT.)	3,000 FT ²
--	-----------------------

FINE ARTS - LANGUAGE ARTS

MUSIC REHEARSAL ROOM	1,400 FT ²
(70 STUDENTS)	
ART LABORATORY	2,000 FT ²
ANCILLARY ROOMS	100-500 FT ²

LANGUAGE ARTS

SMALL THEATRE AND STAGE	3,000 FT ²
ANCILLARY ROOM	400 FT ²

BUSINESS EDUCATION

OFFICE MACHINE LAB	700 FT ²
(20 STUDENTS)	

LECTURE HALLS	1,500-3,000 FT ²
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GENERAL CLASSROOMS

40 STUDENTS	800 FT ²
30 STUDENTS	600 FT ²
20 STUDENTS	400 FT ²

PLANNING AND CIRCULATION

THE SYSTEM MUST ALLOW FOR AN ORDERLY AND FLEXIBLE SYSTEM OF PARTITIONING BY INTEGRATING THE PLANNING MODULE WITH THE STRUCTURAL MODULE. THE MODULE MUST ALLOW FOR FLEXIBLE CIRCULATION OF PEDESTRIAN AND AUTOMOBILE.

STRUCTURE

THE STRUCTURAL SYSTEM SHOULD PROVIDE A UNIFORM PLANNING GRID FOR PARTITIONING. EXCEPT

FOR SPECIAL LARGE SPACES SUCH AS THEATRES, GYMNASIUMS AND AUDITORIUMS, MOST OF THE REQUIRED SPACE SHOULD BE PROVIDED FOR WITHIN THE STRUCTURAL SPAN OF THE SYSTEM.

A CRITICAL FACTOR IN THE ABILITY TO PROVIDE FOR FLEXIBILITY IS THE POSSIBILITY OF FURNISHING NECESSARY MECHANICAL SERVICES. THE STRUCTURAL SYSTEM SHOULD THEREFORE ALLOW FOR A MECHANICAL DISTRIBUTION SYSTEM WHICH IS FLEXIBLE IN INITIAL USE AND ADAPTABLE TO CHANGE FOR FUTURE USE.

MATERIAL

THE USE OF PRECAST CONCRETE IN FORMING THE STRUCTURAL FLOOR SYSTEM COULD ELIMINATE A NEED FOR HUNG CEILINGS AND PROVIDE A UNIFORM PLANNING GRID. THE SYSTEM WOULD BE FIRE RESISTANT AND OF A HIGH DEGREE OF FINISH. AS A PLASTIC MATERIAL, CONCRETE CAN BE READILY SHAPED AND A REAL ECONOMY COULD BE ACHIEVED THROUGH THE USE OF REPETITIVE UNITS CAST IN FORMS WHICH ARE USED MANY TIMES.

MECHANICAL SERVICES

THE DECISION TO DISTRIBUTE MECHANICAL SERVICES WITHIN THE DEPTH OF THE STRUCTURAL

FLOOR SYSTEM WAS IMPLIED IN A PREVIOUS SECTION. WITHIN THIS STRUCTURAL DEPTH, THE FLOOR SYSTEM SHOULD ACCOMMODATE GENERAL MECHANICAL REQUIREMENTS INCLUDING DUCTS FOR HEATING AND AIR CONDITIONING, PIPES FOR HOT AND COLD WATER, SPRINKLERS, WASTE, VENTS AND ROOF DRAINS, TELEPHONE AND ELECTRICAL SERVICES AND SPECIAL SERVICES FOR LABORATORIES.

THE AIR HANDLING SYSTEM SHOULD BE DESIGNED FOR AN AIR CHANGE OF 2 CFM/SQ. FT. THIS WILL PROVIDE FOR THE MAJORITY OF THE SPACES INCLUDING LABORATORY AND ASSEMBLY SPACES.

THERE ARE TWO BASIC ZONES WHICH MUST BE PROVIDED FOR: INTERIOR AND EXTERIOR. INTERIOR ZONES COULD USE SINGLE OR DUAL DUCT SYSTEMS WITH SUPPLY AND RETURN AT THE CEILING. THE DUAL DUCT SYSTEM IS MORE ECONOMICAL TO OPERATE BUT SINGLE DUCT SYSTEMS ARE LESS EXPENSIVE TO INSTALL AND REQUIRE LESS DUCT WORK. EXTERIOR ZONES COULD USE EITHER INDUCTION OR FAN COIL UNITS.

CORE DESIGN AND LOCATION

THE CORES SHOULD PROVIDE FOR VERTICAL CIRCULATION, UTILITY SERVICES, AND POSSIBLY MECHANICAL SERVICES. THEY SHOULD BE

FLEXIBLE ENOUGH TO PROVIDE FOR A WIDE RANGE OF BUILDING TYPES AND OCCUPANCIES. COMBINATIONS SHOULD BE PROVIDED TO ACCOMMODATE ALL OR PART OF THE FOLLOWING SERVICE ELEMENTS: STAIRS, ELEVATORS AND SERVICE ELEVATORS, TOILETS FOR MEN AND WOMEN, AIR SHAFTS, MECHANICAL ZONE ROOMS, ELECTRICAL CLOSETS, TELEPHONE CLOSETS, JANITOR CLOSETS, GENERAL BUILDING CLOSETS, FIRE-FIGHTING STAND PIPES.

THE REQUIREMENTS FOR VARIOUS SERVICE ELEMENTS ARE GIVEN BELOW. THEY ARE APPROXIMATE AND WILL VARY WITH OCCUPANCIES.

PASSENGER ELEVATORS	- ONE 5' X 7'6" ELEVATOR PER 50,000 SQ. FT. NET FLOOR AREA
ELECTRICAL CLOSETS	- 25 FT ² /30,000 FT ² GROSS FLOOR AREA
TELEPHONE CLOSETS	- 100 FT ² /30,000 FT ² GROSS FLOOR AREA
JANITOR CLOSETS	- 25 FT ² /30,000 FT ² GROSS FLOOR AREA
TOILET FIXTURES (WOMEN)	- 1 W.C./45 1 LAV./100
TOILET FIXTURES (MEN)	- 1 W.C./100 1 LAV./100 1 URINAL/30

FIRE STAIRS SHOULD BE PROVIDED FOR

DIFFERENT OCCUPANCIES AT A FREQUENCY AND WIDTH AS REQUIRED BY THE NATIONAL BUILDING CODE. THE OCCUPANCIES PROVIDED FOR SHOULD INCLUDE:⁷

EDUCATIONAL - 1 PERSON PER 40 SQ. FT.

BUSINESS - 1 PERSON PER 100 SQ. FT.

HIGH HAZARD

THE UNIT OF STAIRWAY WIDTH USED AS A MEASURE OF EXIT CAPACITY IS 22 INCHES. THE NUMBER OF OCCUPANTS PER STORY PER UNIT OF EXIT STAIRWAY WIDTH IS:

EDUCATIONAL - 60

BUSINESS - 60

HIGH HAZARD - 30

EXIT DOORWAYS SHOULD BE SO LOCATED THAT THE MAXIMUM DISTANCE FROM ANY POINT IN A FLOOR AREA, ROOM OR SPACE TO AN EXIT DOORWAY, MEASURED ALONG THE LINE OF TRAVEL DOES NOT EXCEED:

-100 FEET FOR EDUCATIONAL OCCUPANCIES

-150 FEET FOR BUSINESS OCCUPANCIES

-75 FEET FOR HIGH HAZARD OCCUPANCIES

LIGHTING AND ACOUSTICS

FLORESCENT LIGHT FIXTURES AND ACOUSTICAL

TREATMENT SHOULD BE COORDINATED WITH THE PLANNING AND STRUCTURAL GRIDS. VARIOUS COMBINATIONS AND PATTERNS SHOULD BE PROVIDED TO MEET VARIOUS CONDITIONS AND PROVIDE FOR VARIOUS DEGREES OF FINISH. PROVISIONS SHOULD BE MADE FOR SOUND ISOLATION AND FOR ALTERING THE ACOUSTICAL CHARACTERISTICS OF SPACES (SOUND INTENSITY LEVEL AND REVERBERATION TIME).

PRELIMINARY PROPOSAL

THE BASIC CHOICES IN STRUCTURAL SYSTEMS ARE ONE-WAY AND TWO-WAY OR SPACE GRID SYSTEMS. THE CHOICE RESULTS IN MORE FLEXIBILITY IN ONE DIRECTION OR EQUAL FLEXIBILITY IN TWO DIRECTIONS. WITH KNOWLEDGE OF THE POSSIBILITIES OF INCREASED LABOR COSTS, THE TWO-WAY AND SPACE GRID SYSTEMS WERE CHOSEN FOR INVESTIGATION BECAUSE OF THE TWO DIRECTIONAL FREEDOM.

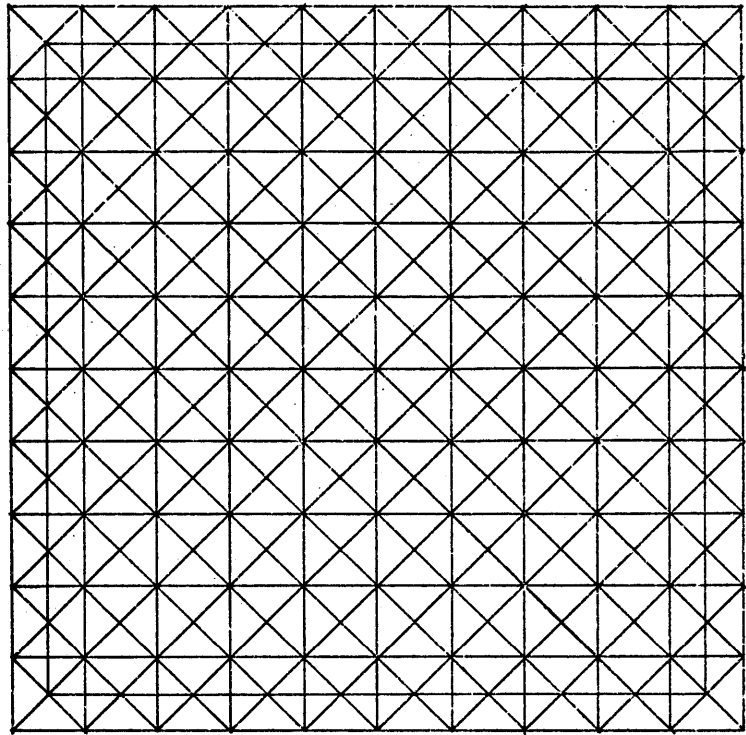
BECAUSE OF THE ABILITY OF SPACE GRID STRUCTURAL SYSTEMS TO DISTRIBUTE EXTERNAL LOADS IN MANY DIRECTIONS AMONG NUMEROUS STRUCTURAL MEMBERS, A NEAR EVEN STRESS DISTRIBUTION RESULTS. THIS EVEN STRESS DISTRIBUTION ALLOWS FOR A REDUCTION IN THE RATIO OF WEIGHT TO AREA COVERED BY THE STRUCTURE AND THEREFORE REPRESENTS A SAVINGS IN MATERIAL AND SPACE. AS A RESULT THESE SYSTEMS ARE CAPABLE OF ACCOMMODATING A LARGE AMOUNT OF MECHANICAL SERVICES WITHIN THEIR STRUCTURAL DEPTH.

THERE ARE THREE BASIC TYPES OF SPACE GRID STRUCTURES: TWO-WAY, THREE-WAY, AND FOUR-WAY. THE TWO-WAY SPACE GRIDS ARE GENERALLY

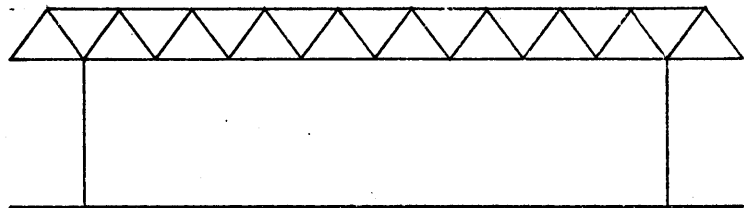
COMPOSED OF SQUARE PYRAMIDS AND ARE PARTICULARLY SUITABLE FOR BUILDINGS OF RECTANGULAR LAYOUT. THE THREE-WAY AND FOUR-WAY SPACE GRIDS ARE STRONGER SYSTEMS AND SUITABLE FOR VERY LARGE SPANS BUT THEY GENERALLY DO NOT PROVIDE FOR RECTANGULAR PLANNING.

TWO-WAY SPACE GRID STRUCTURES ARE UNIFORM IN DENSITY. THE VOIDS WITHIN THE STRUCTURE ARE ALSO UNIFORM AND DO NOT PROVIDE AN IDEAL SEQUENCE OF SPACE FOR PRIMARY AND SECONDARY MECHANICAL DISTRIBUTION. (SEE FIGURE 1)

WHILE WORKING WITH THE TWO-WAY SPACE GRID STRUCTURES IT WAS DISCOVERED THAT BY SHIFTING THE VERTEX OF THE PYRAMID UNITS THE ENTIRE MASS OF THE SYSTEM COULD BE SHIFTED. (SEE FIGURE 2) TWO DISTINCT ADVANTAGES WERE FOUND IN A SYSTEM COMPOSED OF THESE UNITS. FIRST, THE NEW UNITS COULD BE ARRANGED TO FORM COLUMN CAPITALS AND GIRDERS. SECONDLY, THE VOID LEFT AT THE CENTER OF THE BAY PROVIDED A LARGE SPACE FOR PRIMARY MECHANICAL DISTRIBUTION. (SEE FIGURES 3, 4 AND 5)

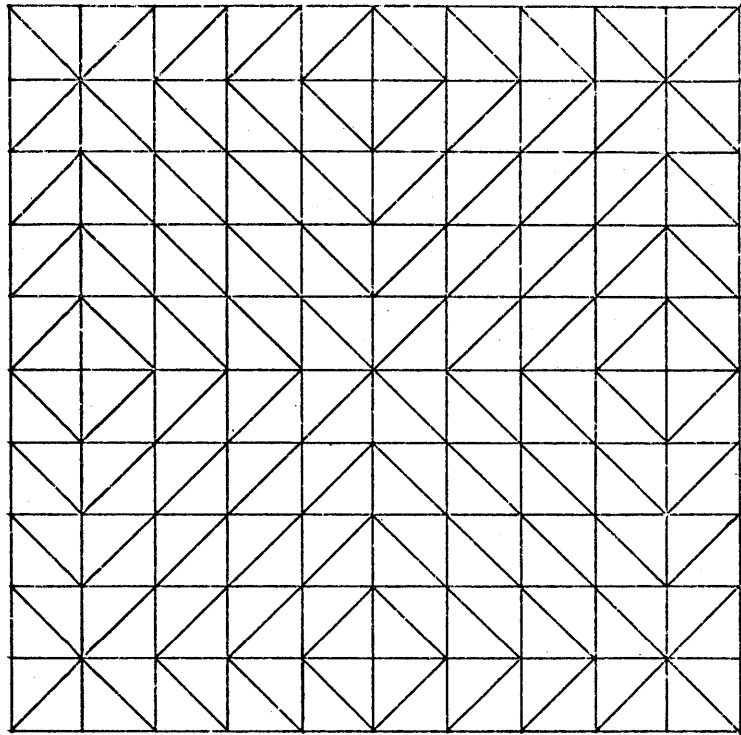


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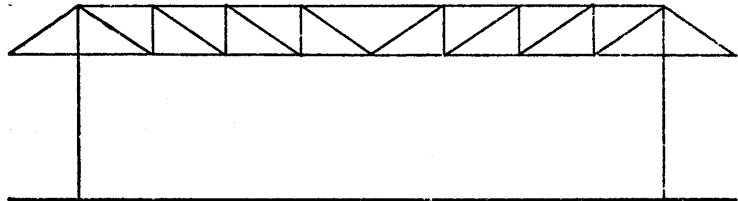


ELEVATION

FIGURE 1. TWO-WAY SPACE GRID SYSTEM
MADE OF PYRAMID UNITS.

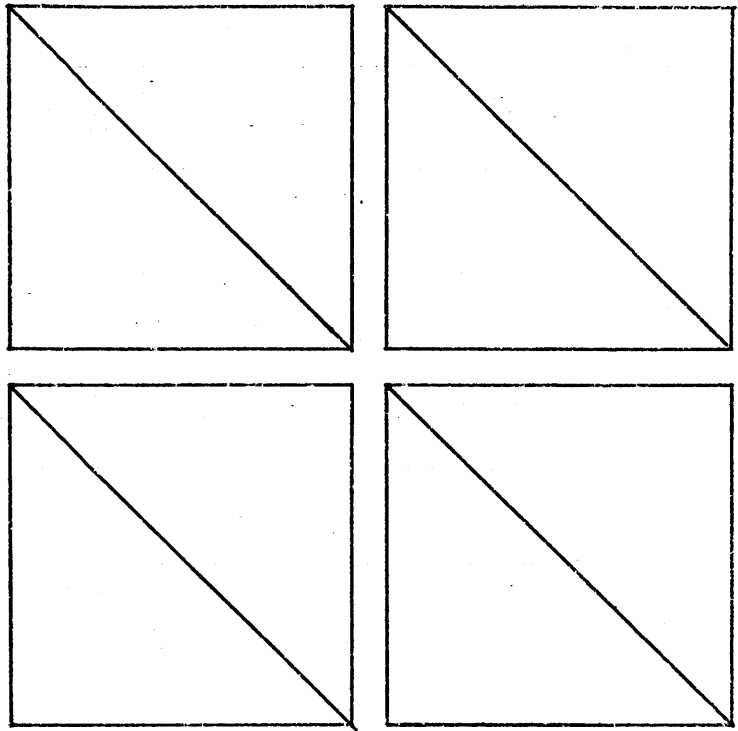


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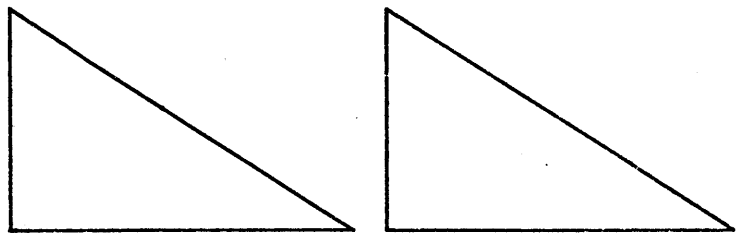


ELEVATION

FIGURE 2. TWO-WAY SPACE GRID SYSTEM
MADE OF PYRAMID UNITS WITH VERTEX
SHIFTED.

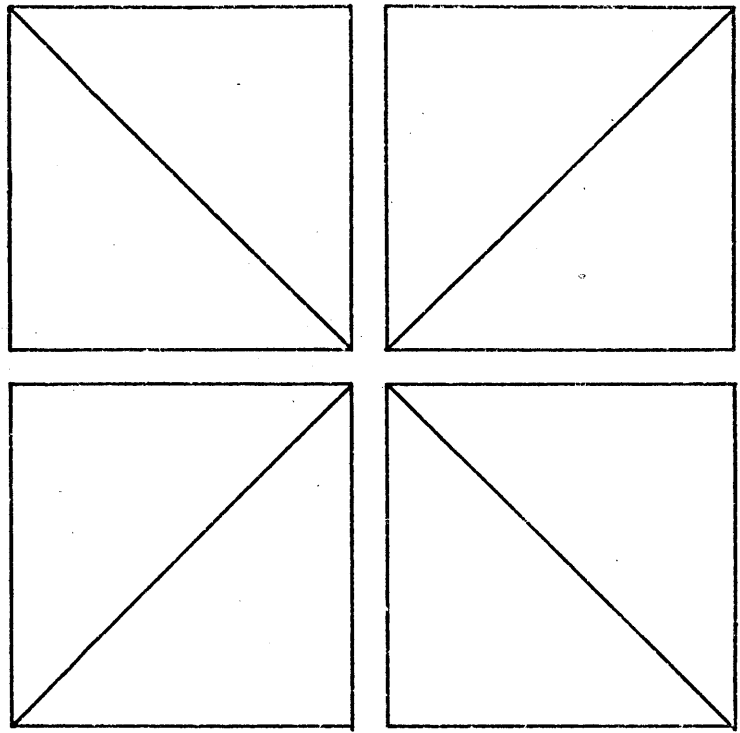


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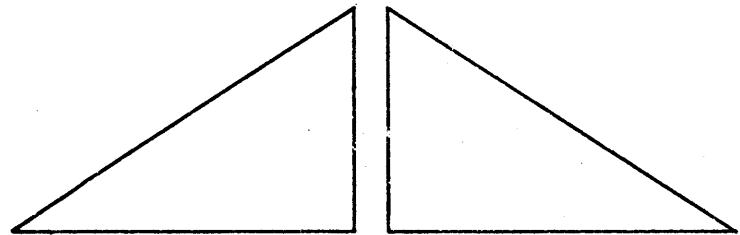


ELEVATION

FIGURE 3. TYPICAL UNIT ARRANGEMENT.

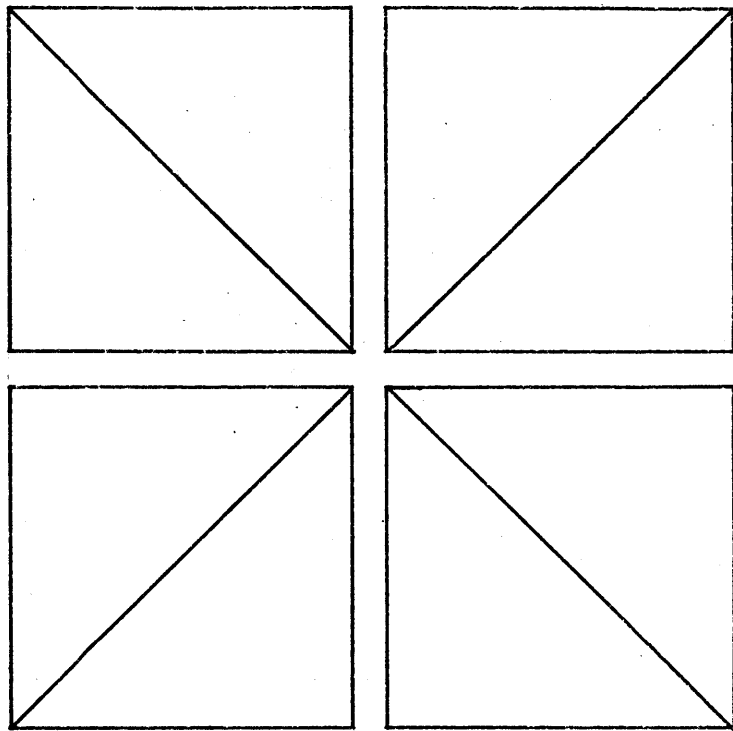


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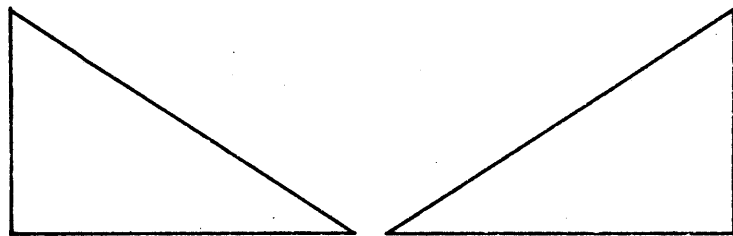


ELEVATION

FIGURE 4. UNIT ARRANGEMENT AT
COLUMN CAPITAL.



PLAN



ELEVATION

FIGURE 5. UNIT ARRANGEMENT AT
CENTER OF BAY.

A 6' X 6' MODULE AND 48' X 48' STRUCTURAL BAY WAS FOUND TO BEST PROVIDE FOR THE VARIOUS REQUIREMENTS OF THE SYSTEM. THIS ESTABLISHED A NOMINAL DIMENSION OF 6' X 6' FOR THE WIDTH OF THE STRUCTURAL COMPONENT.

WITH THE LARGEST VOID AT THE CENTER LINES OF THE STRUCTURAL BAY, COLUMN SUPPLY OF MECHANICAL SERVICES WAS RULED OUT AND CORE SUPPLY WAS INVESTIGATED. PRELIMINARY MECHANICAL DISTRIBUTION PATTERNS AND CALCULATIONS OF DUCT SIZES ESTABLISHED THE NEED FOR A STRUCTURAL DEPTH OF 4 FEET. A SELF-SUFFICIENT STRUCTURAL, MECHANICAL CIRCULATORY UNIT OF 144' X 144' WAS ESTABLISHED. THE CORE WAS PLACED IN THE CENTRAL BAY OF THIS UNIT AND CONTAINED VERTICAL CIRCULATION, UTILITY AND MECHANICAL SERVICE ELEMENTS.

IN THE DEVELOPMENT OF THE DETAILS FOR THIS SYSTEM, THE STRUCTURAL COMPONENTS WERE PLACED SIDE BY SIDE AND SPACE WAS LEFT BETWEEN ADJACENT BOTTOM CHORDS FOR GROUTING AND POST-TENSIONING. THIS RESULTED IN A LARGER BUILD-UP OF MATERIAL THAN WAS

STRUCTURALLY NECESSARY. IN ADDITION, THE UNITS THEMSELVES PROVED TO BE OF A GEOMETRY THAT WOULD BE DIFFICULT TO FORM IN CONCRETE. IT WAS THEREFORE DECIDED THAT THE SYSTEM COULD BEST BE CONSTRUCTED OF ANOTHER MATERIAL AND THE SEARCH BEGAN FOR A SYSTEM MORE APPLICABLE TO CONCRETE TECHNOLOGY.

(SEE PHOTOGRAPHS OF PRELIMINARY PROPOSAL)

FINAL PROPOSAL

THE PURPOSE OF THE FINAL PROPOSAL WAS TO DEVELOP A STRUCTURAL SYSTEM WHICH COULD BE MORE EASILY FORMED IN CONCRETE AND USED LARGER AND FEWER PRECAST UNITS THAN THE PRELIMINARY PROPOSAL.

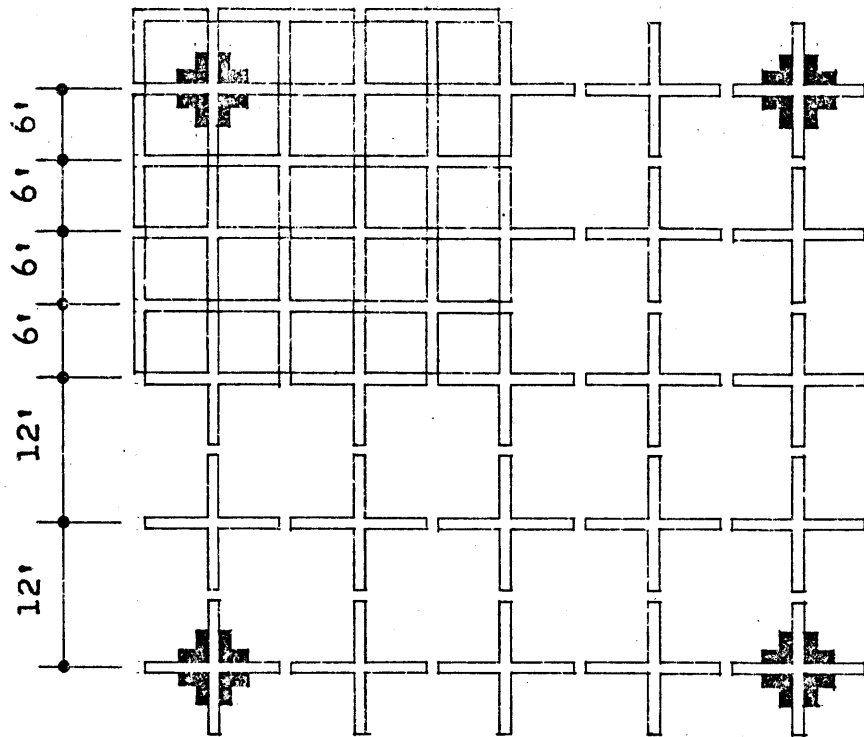
TO ESTABLISH A PROPER BAY SIZE AND PLANNING-STRUCTURAL MODULE, SEVERAL UNIVERSITY PLANS AND THE SPACE REQUIREMENTS PREVIOUSLY LISTED WERE STUDIED. IT WAS FOUND THAT BAY SIZES IN A RANGE FROM 40' TO 60' COULD PROVIDE THE NECESSARY DESIGN AND PLANNING FLEXIBILITY. A 6' X 6' MODULE AND 48' X 48' STRUCTURAL BAY WAS FOUND TO BEST PROVIDE FOR THE VARIOUS REQUIREMENTS OF THIS SYSTEM.

THE SYSTEM PRESENTED IS DESIGNED FOR AN EIGHT FLOOR BUILDING HEIGHT, BUT BOTH THE COLUMNS AND MECHANICAL SPACE CAN BE ENLARGED OR REDUCED TO HANDLE A FEWER OR GREATER NUMBER OF FLOORS. THE MECHANICAL SPACE PROVIDED AT THE COLUMNS ALLOWS FOR 4 FLOORS TO BE SUPPLIED FROM THE ROOF AND 4 FROM THE GROUND LEVEL.

STRUCTURE

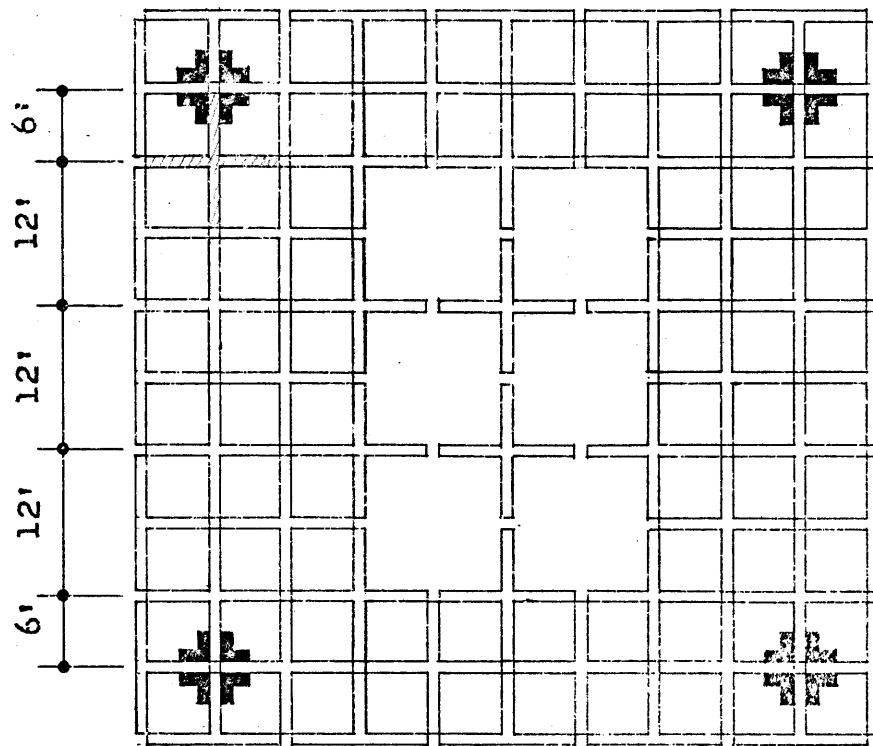
THE STRUCTURAL BAY CONSISTS OF A TWO-WAY PRECAST CONCRETE FLOOR SYSTEM SUPPORTED ON FOUR COLUMNS 48' ON CENTERS. THE FLOOR SYSTEM CONSISTS OF TWO BASIC UNITS: A CROSS-SHAPED BOTTOM CHORD AND A CROSS-SHAPED DIAGONAL WEBB MEMBER. THE NOMINAL DIMENSION OF THESE UNITS IS 12' X 12' BUT THEY MAY BE ASSEMBLED IN A MANNER WHICH PROVIDES EITHER A 6' X 6' OR A 12' X 12' PLANNING MODULE. (SEE FIGURES 6 AND 7)

THE COLUMNS ARE COMPOSED OF FOUR PRECAST UNITS USED AS FORMWORK FOR THE POURED-IN-PLACE CONCRETE WHICH TIES THEM TOGETHER. THE FOUR PRECAST COLUMN UNITS ARE PLACED ON STEEL LEVELING BLOCKS AND GROUTED. THE SPACE BETWEEN THE FOUR PRECAST UNITS THEN RECEIVES REINFORCING STEEL AND CONCRETE IS POURED TO A LEVEL JUST BELOW THE DESIRED CEILING HEIGHT. A PRECAST COLUMN CAPITAL IS PLACED IN THE SPACE REMAINING. A TOLERANCE OF ONE AND A HALF INCHES IS PROVIDED BETWEEN THE COLUMN UNITS AND THE



PLAN

FIGURE 6. DIAGONAL WEBB UNIT ARRANGEMENT. THIS ARRANGEMENT PLACES THE COLUMNS AT THE CENTER OF THE DIAGONAL WEBB UNITS AND ALLOWS FOR A 6' X 6' OR 12' X 12' MODULE.



PLAN

FIGURE 7. DIAGONAL WEBB UNIT ARRANGEMENT. THIS ARRANGEMENT PLACES THE COLUMNS AT THE ENDS OF THE DIAGONAL WEBB UNITS. IT ALLOWS FOR A 12' X 12' MODULE ONLY IN THE PATTERN SHOWN. THIS ARRANGEMENT WAS CHOSEN FOR DEVELOPMENT BECAUSE OF A BETTER VOID RELATIONSHIP FOR COLUMN SUPPLY AND RETURN OF MECHANICAL SERVICES.

COLUMN CAPITAL. THIS SPACE IS GROUTED AFTER THE SYSTEM IS POST-TENSIONED.

THE BOTTOM CHORD AND DIAGONAL WEBB UNITS ARE PRECAST WITH POST-TENSIONING DUCTS IN THEM. THEY ARE PLACED ON SCAFFOLDING, ALIGNED AND POST-TENSIONING CABLES ARE THREADED THROUGH THEM. THE BEARING SURFACES ARE THEN GROUTED, THE BOTTOM CHORDS POST-TENSIONED AND POST-TENSIONING CABLES PRESSURE GROUTED. PRECAST FLOOR SLABS, SLAB REINFORCING AND UTILITY RACEWAYS ARE PLACED AND CONCRETE TOPPING IS POURED TO COMPLETE THE SYSTEM.

THE COLUMNS ARE MADE CONTINUOUS FROM FLOOR TO FLOOR BY WELDING. REINFORCING EXTENDS ABOVE THE TOP OF THE PRECAST COLUMN UNITS AND IS WELDED TO STEEL PLATES AT THE BASE OF THE COLUMN UNITS ABOVE. FURTHER CONTINUITY IS OBTAINED BY PASSING REINFORCING FROM COLUMN TO COLUMN THROUGH HOLES PREPARED IN THE COLUMN CAPITAL.

TWO MAJOR DIFFICULTIES IN POST-TENSIONED SYSTEMS LIE AT THE JOINTS BETWEEN THE

MEMBERS. FIRST, DEVIATIONS IN THE POSITIONING OF THE PRECAST UNITS REQUIRE ENLARGEMENTS OF THE HOLES FOR POST-TENSIONING CABLES AT THE JOINTS. SECOND, THERE IS AN UNEVEN TRANSFER OF COMPRESSIVE FORCES AT THE JOINTS. THESE PROBLEMS ARE SOLVED BY OVER-DIMENSIONING THE PRECAST UNITS AT THE JOINTS.

MECHANICAL SERVICES

BECAUSE OF THE SIZE AND GEOMETRY OF THE VOIDS WITHIN THE STRUCTURAL FLOOR SYSTEM, COLUMN SUPPLY AND RETURN WAS CHOSEN. THE LARGEST VOID WITHIN THE STRUCTURAL FLOOR SYSTEM RUNS DIAGONALLY FROM COLUMN TO COLUMN. THEREFORE, FOR ALL SYSTEMS, PRIMARY HORIZONTAL MECHANICAL SERVICE LINES RUN DIAGONALLY FROM THE COLUMNS AND SECONDARY SERVICE LINES RUN PARALLEL WITH THE STRUCTURAL AND PLANNING GRID.

THE AIR SYSTEM IS A SINGLE DUCT TERMINAL REHEAT SYSTEM. AIR IS SUPPLIED VERTICALLY AT 6,000 FPM AND IS REDUCED TO 1,200 FPM

BY PASSING IT THROUGH A VELOCITY AND SOUND ATTENUATOR AS IT ENTERS THE FLOOR SYSTEM. IT IS DAMPERED AT THE DIFFUSER AND DISTRIBUTED AT 600 FPM. AIR IS SUPPLIED COLD AND HEATED BY ELECTRIC COILS AT THE DIFFUSER OR SOUND ATTENUATOR, DEPENDING ON THE AREA OF THE SPACE ZONED. SUPPLY AND RETURN AIR IS DISTRIBUTED ALTERNATELY OVER THE 6' MODULES. AIR IS RETURNED HORIZONTALLY AND VERTICALLY AT 1,200 FPM.

PRIMARY HORIZONTAL PLUMBING LINES INCLUDING PIPES FOR HOT AND COLD WATER, WASTE, VENT AND ROOF DRAINS RUN DIAGONALLY FROM THE COLUMNS. VENTS AND WET PIPING TO TOILETS ARE CONTAINED IN THE SERVICE CORES.

TELEPHONE AND ELECTRICAL SERVICES ARE PROVIDED IN RACEWAYS IN THE CONCRETE TOPPING AT THE CENTER OF EACH MODULE.

CORE DESIGN AND CIRCULATION

A TYPICAL CORE IS COMPOSED OF VARIOUS CORE ELEMENTS DEPENDING ON THE OCCUPANCY AND AREA SERVED. THE CORE SERVES AS THE BASIC

ORGANIZATIONAL ELEMENT AND PROVIDES FOR VERTICAL CIRCULATION AND SERVICE NEEDS. THE AREA OF INFLUENCE OF A CORE IS BASED ON EXIT REQUIREMENTS TAKEN FROM THE NATIONAL BUILDING CODE. CORE ARRANGEMENTS AND CORE SPACINGS ARE PROVIDED FOR EDUCATIONAL, BUSINESS AND HIGH HAZARD OCCUPANCIES. THEY ARE INCLUDED IN THE DRAWINGS AT THE END OF THIS REPORT.

THE CORES ARE CONSTRUCTED BEFORE THE PRECAST COLUMN AND FLOOR SYSTEM IS ERECTED. TWO VERTICAL SHAFTS (STAIR, SERVICE OR ELEVATOR ELEMENTS) ARE POURED IN PLACE AND A FLAT FLOOR SLAB IS POURED BETWEEN THEM. THE FLAT SLAB ALLOWS FOR A LOWER CEILING AND SPECIAL MECHANICAL REQUIREMENTS IN THE TOILET AND SERVICE ELEMENTS BETWEEN THE TWO VERTICAL SHAFTS. THE PRECAST FLOOR SYSTEM IS USED WHEN CIRCULATION OCCURS BETWEEN THE TWO VERTICAL SHAFTS. THE SYSTEM IS POST-TENSIONED INTO THE SHAFTS IN ONE DIRECTION AND INTO THE FLOOR SYSTEM OF ADJACENT BAYS IN THE OTHER DIRECTION.

LATERAL STABILITY IS PROVIDED FOR THE

STRUCTURAL SYSTEM BY TYING THE COLUMNS TO THE CORES AT THE CORNERS OF THE VERTICAL SHAFTS.

LIGHTING AND ACOUSTICS

SOUND TRANSFER THROUGH THE FLOOR SYSTEM CAN BE STOPPED BY EITHER HORIZONTAL OR VERTICAL ELEMENTS. BOTH PROCEDURES ARE EMPLOYED IN THIS SYSTEM. HORIZONTAL SOUND BARRIERS CONSIST OF METAL PANELS AT EACH 6' X 6' MODULE. EACH METAL PANEL ENCLOSES AN INTEGRATED UNIT CONSISTING OF LIGHT DIFFUSER, AIR DIFFUSER, AND ACOUSTICAL PANEL. THE ACOUSTICAL CHARACTERISTICS OF SPACE (SOUND INTENSITY LEVELS AND REVERBERATION TIME) CAN BE ALTERED BY USING DIFFERENT COMBINATIONS OF SOUND ABSORBING OR SOUND REFLECTING PANELS WITHIN THE UNIT.

EACH UNIT WILL ACCOMMODATE STANDARD 4 FEET LONG FLORESCENT TUBES. TWO BASIC ARRANGEMENTS CAN BE USED TO ACHIEVE 68 F.C. THE FIRST ARRANGEMENT HAS THREE 40 WATT LUMINAIRES IN EACH 6' X 6' MODULE AND THE SECOND HAS SIX 40 WATT LUMINAIRES IN EVERY ALTERNATE

6' X 6' MODULE.

VERTICAL SOUND BARRIERS CONSIST OF PLASTER DIAPHRAMS INSERTED IN THE STRUCTURAL VOIDS ALONG PARTITIONING LINES. A STANDARD LIGHT AND AIR DIFFUSING UNIT CAN BE USED WITH THIS SYSTEM. THE STRUCTURAL AND MECHANICAL SYSTEM IS EXPOSED AND ACOUSTICAL PANELS ARE PLACED ON THE UNDER SIDE OF THE PRE-CAST FLOOR SLABS.

CONSTRUCTION SEQUENCE

1. FOUNDATIONS FOR COLUMNS POURED
2. CORES ERECTED
3. PRECAST COLUMN ELEMENTS PLACED ON STEEL LEVELING BLOCKS, WELDED AND GROUTED
4. STEEL PLACED BETWEEN PRECAST COLUMN ELEMENTS AND CONCRETE POURED
5. SCAFFOLDING ERECTED
6. COLUMN CAPITALS, BOTTOM CHORD AND DIAGONAL WEBB UNITS POSITIONED ON SCAFFOLDING
7. POST-TENSION CABLES THREADED THROUGH PRECAST UNITS.
8. BEARING SURFACES GROUTED

9. BOTTOM CHORDS POST-TENSIONED
10. POST-TENSIONING CABLES PRESSURE
GROUTED
11. PRECAST FLOOR SLABS PLACED
12. SLAB REINFORCING AND UTILITY RACE-
WAYS PLACED
13. CONCRETE TOPPING POURED
14. REPETITION OF PROCEDURES FROM 3 TO 13

(SEE PHOTOGRAPHS OF FINAL PROPOSAL)

CONCLUSION

IN THE DEVELOPMENT OF THIS PROBLEM EMPHASIS WAS PLACED ON THE DESIGN OF A STRUCTURAL FLOOR SYSTEM THAT WOULD TAKE ADVANTAGE OF THE SAVINGS IN MATERIAL THAT SPACE GRID SYSTEMS HAVE DEMONSTRATED.

THE PRESENT TREND IN THE CONSTRUCTION INDUSTRY IS TOWARD LARGER PREFABRICATED UNITS AND LARGER PIECES OF CONSTRUCTION EQUIPMENT ARE BEING PRODUCED TO HANDLE THESE UNITS. DESPITE AN ATTEMPT TO INCREASE THE SIZE AND REDUCE THE NUMBER OF STRUCTURAL ELEMENTS, THE STRUCTURAL SYSTEM DESIGNED IS STILL COMPOSED OF A LARGE NUMBER OF RELATIVELY SMALL PRECAST ELEMENTS. THE ECONOMIC SUCCESS OF THIS SYSTEM WOULD DEPEND ON THE SAVINGS IN MATERIAL TO OFFSET AN INCREASED COST IN LABOR DUE TO THE LARGE NUMBER OF ELEMENTS WHICH MUST BE HANDLED.

THE IDEA OF A TOTALLY INDUSTRIALIZED BUILDING SYSTEM WAS NOT REALIZED IN THIS PROBLEM BECAUSE OF THE TIME REQUIRED FOR THE DESIGN OF THE BASIC STRUCTURAL SYSTEM. FOR THIS SYSTEM TO BE EFFECTIVE A MORE

COMPLETE DEVELOPMENT OF THE SUB-SYSTEMS
WOULD BE REQUIRED. THERE WOULD ALSO
HAVE TO BE A LARGE ENOUGH MARKET TO
ENABLE MANUFACTURERS TO PRODUCE THESE
SUB-SYSTEMS.

APPENDIX A

CALCULATIONS

APPENDIX B

COMPUTER SUPPLEMENT

AS A CLASS PROJECT A COMPUTER PROGRAM ENTITLED "COMPUTER SUPPLEMENT FOR INTEGRATED BUILDING SYSTEMS" WAS DEVELOPED. THIS PROGRAM WAS DEVELOPED TO SUPPLEMENT THE GRADUATE PROGRAM IN BUILDING SYSTEMS.

THE PROBLEM TO BE SOLVED WAS THE INTEGRATION OF STRUCTURAL, LIGHTING, AND MECHANICAL VARIABLES INTO A WORKABLE PROTOTYPE BUILDING SYSTEM. THE SOLUTIONS ARE IN BOTH WRITTEN AND GRAPHIC FORM. A COPY OF THE PROGRAM IS AVAILABLE FOR REFERENCE IN THE ROTCH LIBRARY, M.I.T.

FOOTNOTES

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- 2 IBID.
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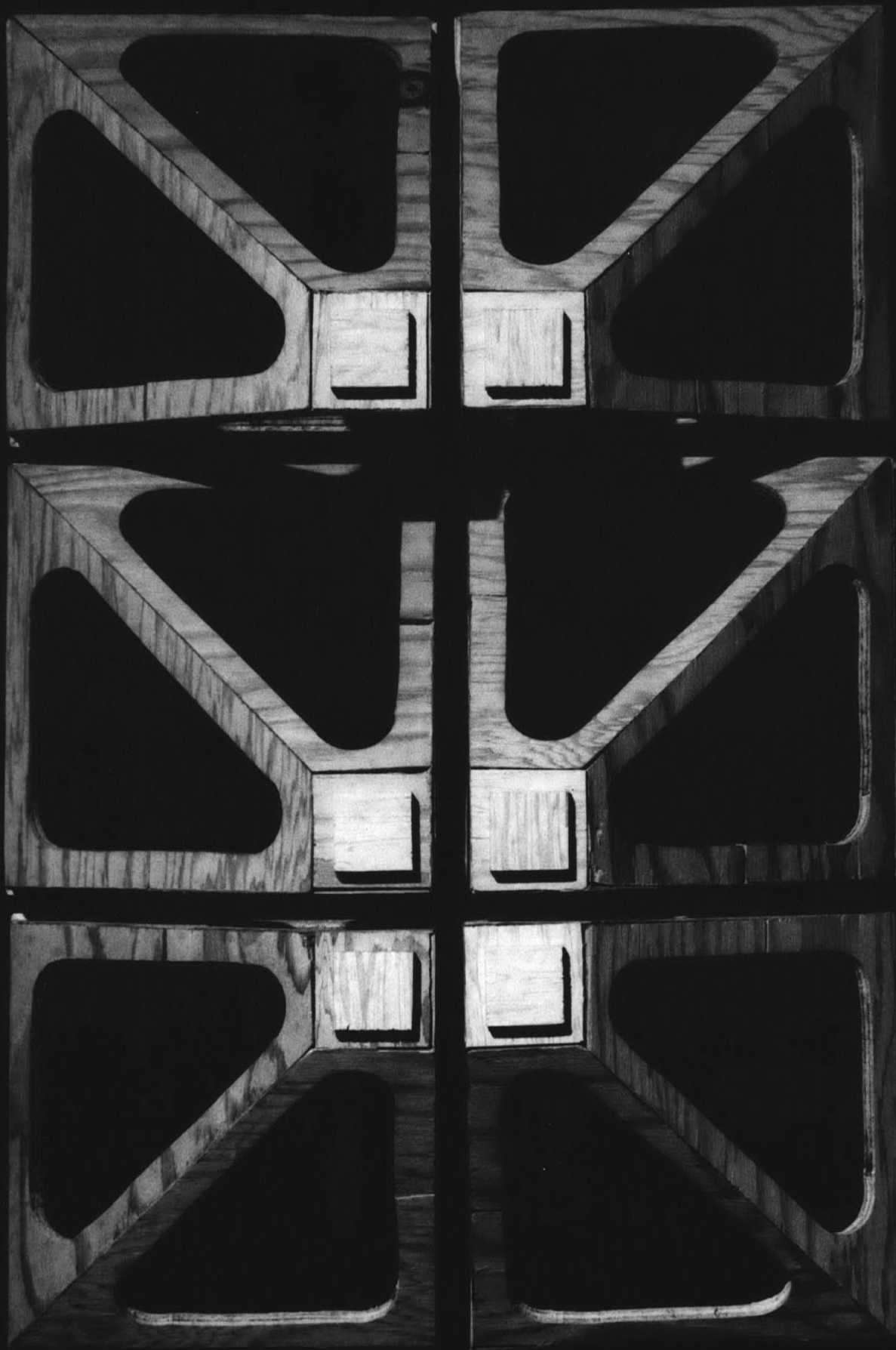
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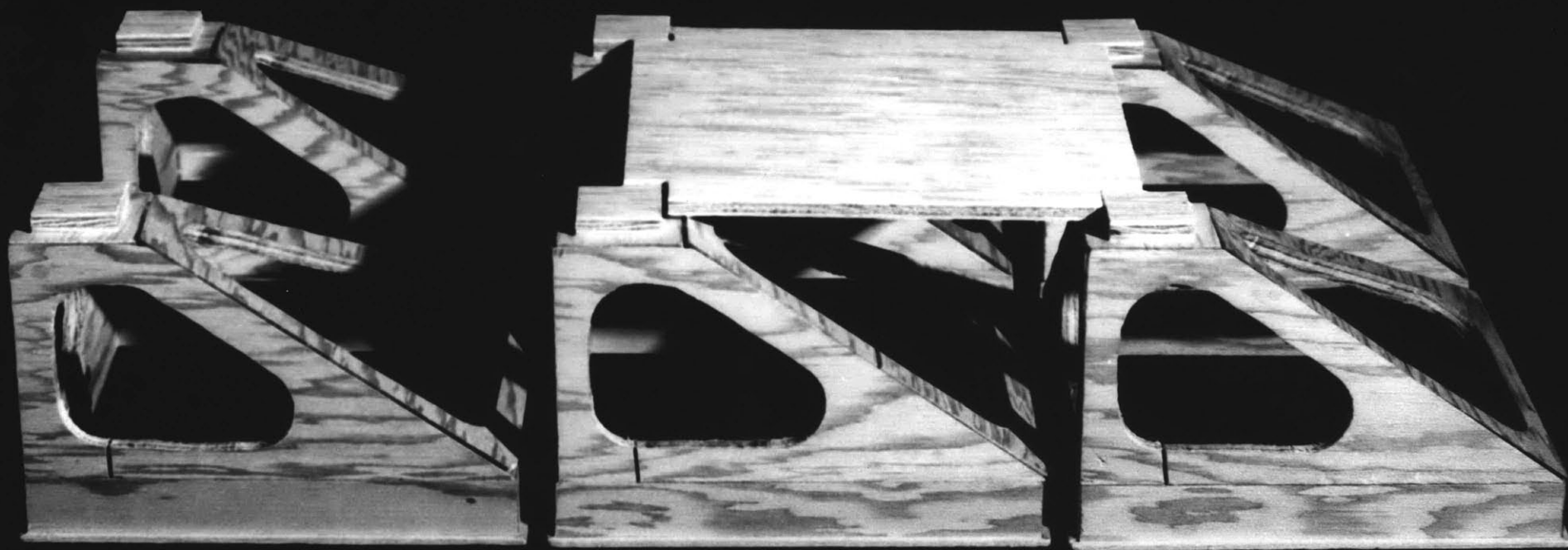
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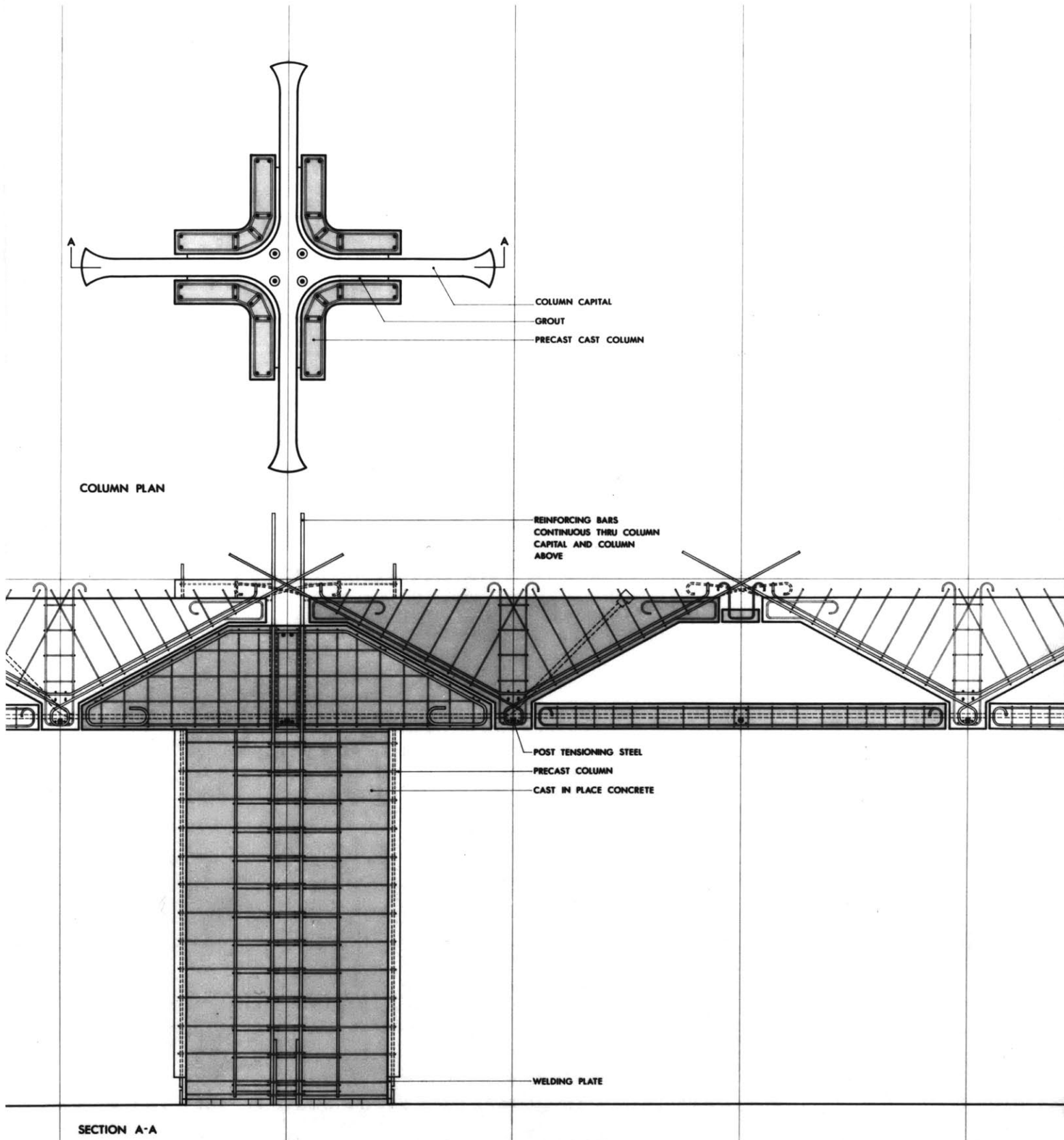




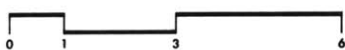




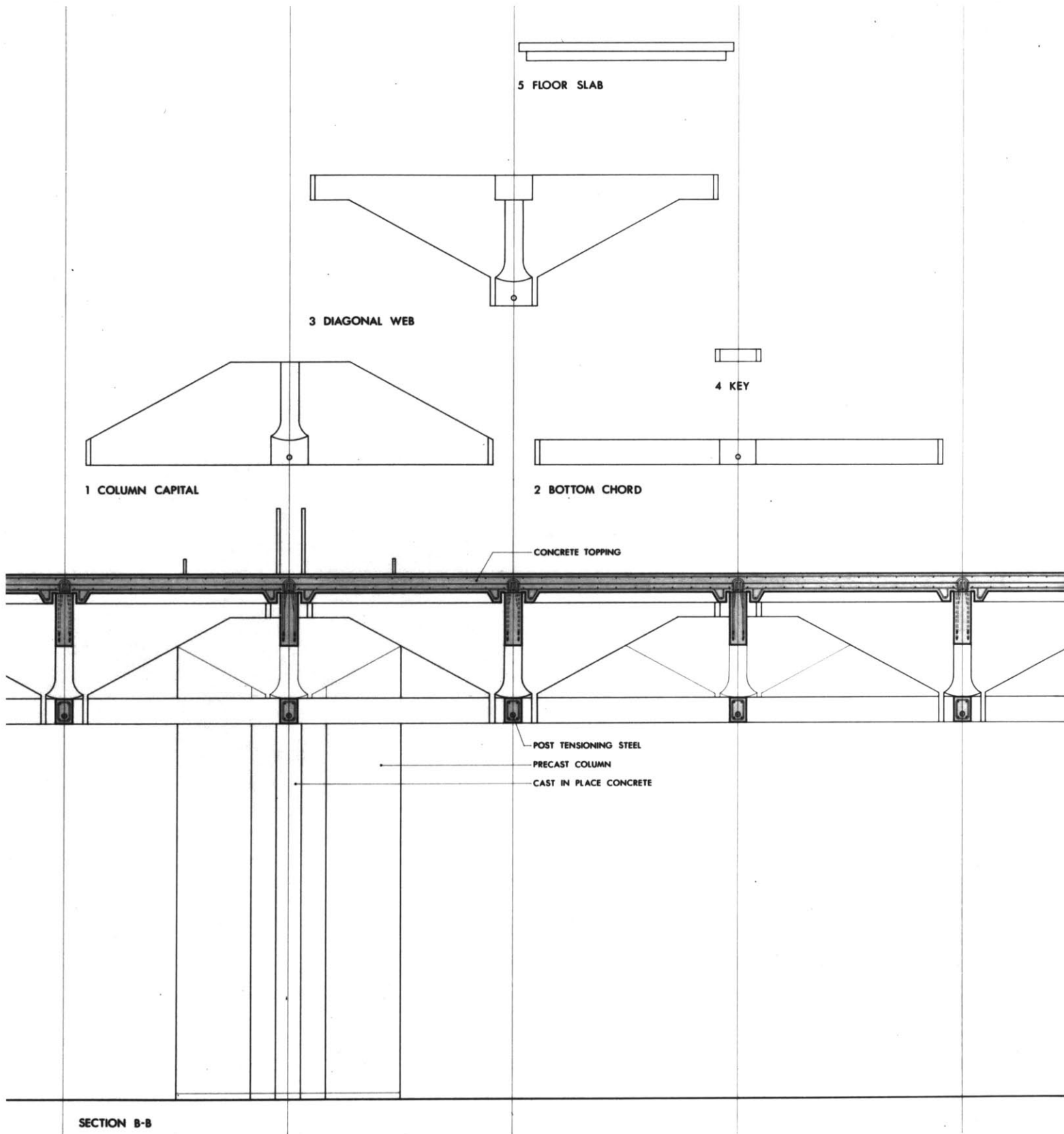
PHOTOGRAPHS OF FINAL PROPOSAL



STRUCTURAL DETAILS

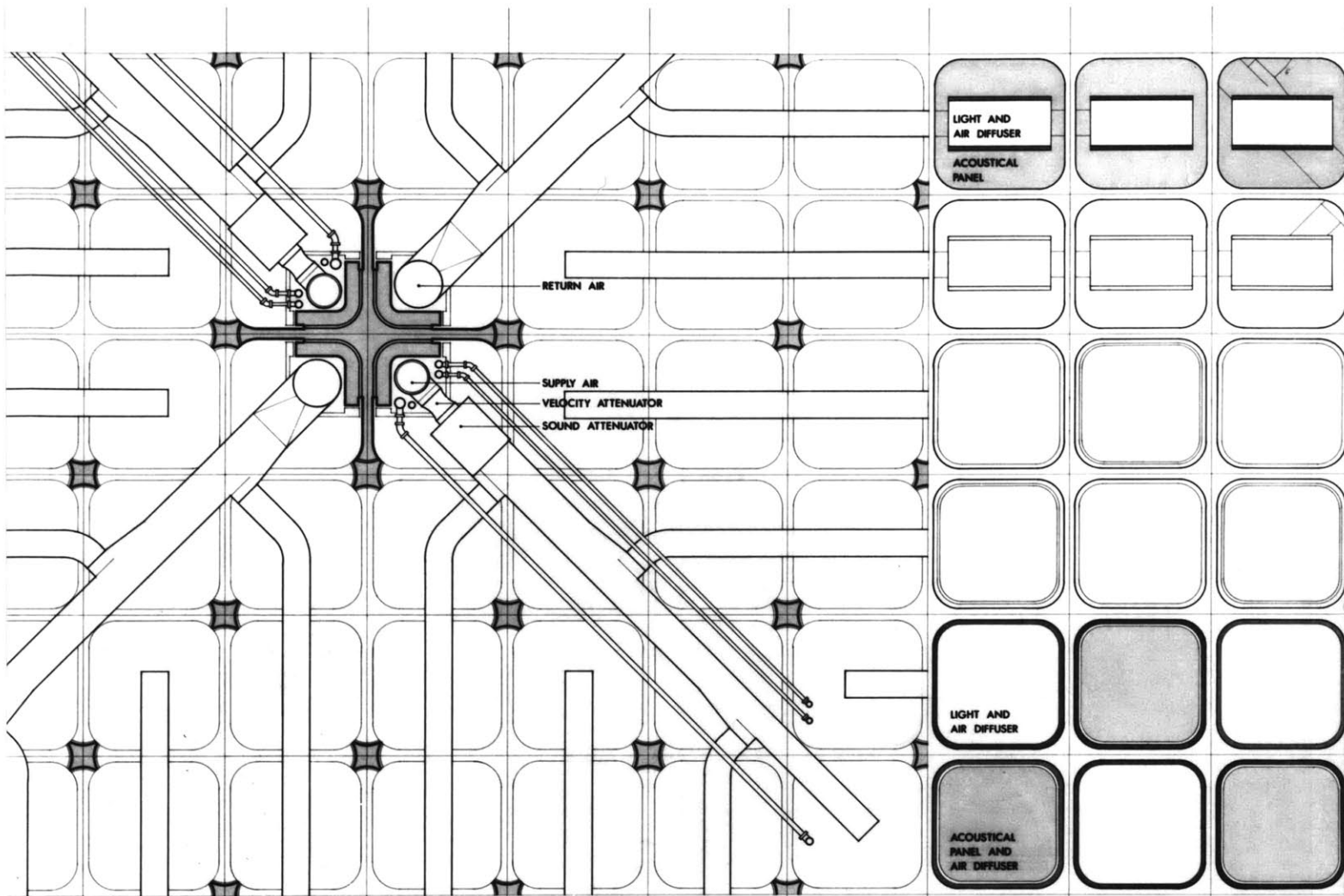


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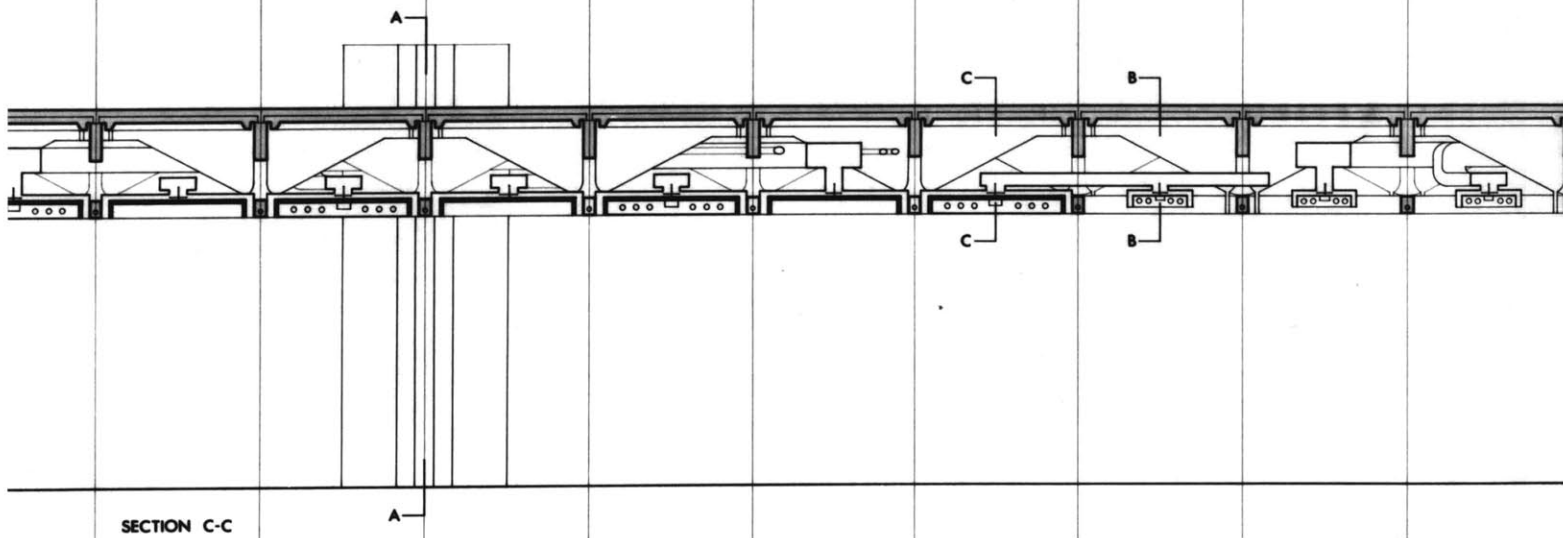
STRUCTURAL DETAILS
COMPONENTS

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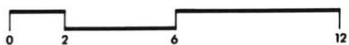


PLAN SECTION THRU STRUCTURE

REFLECTED CEILING PLAN

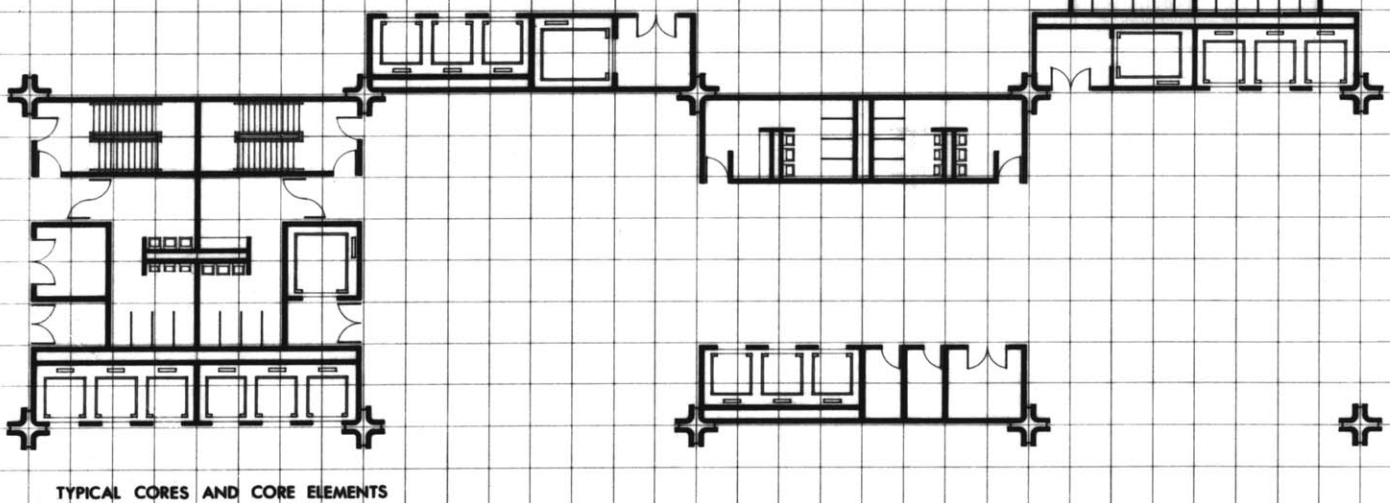
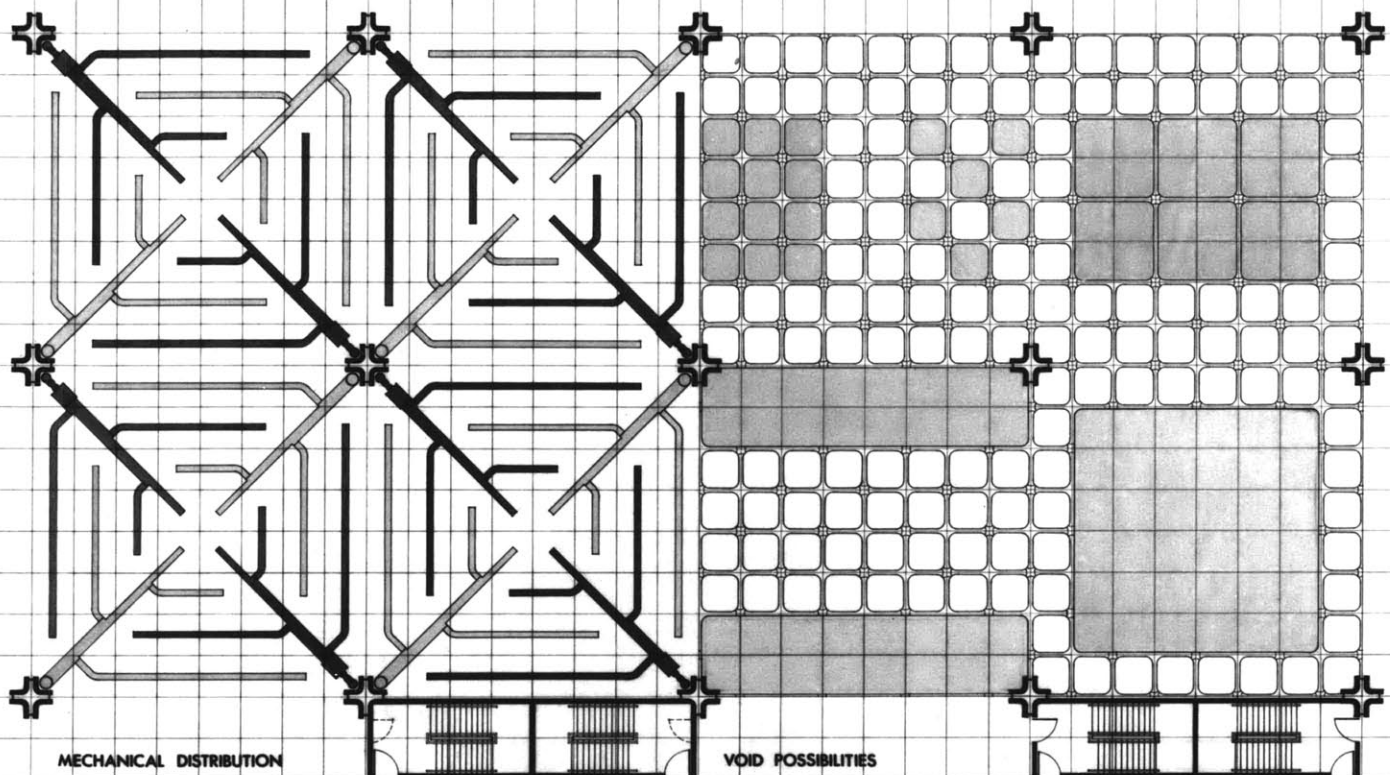


STRUCTURAL MECHANICAL
INTEGRATION



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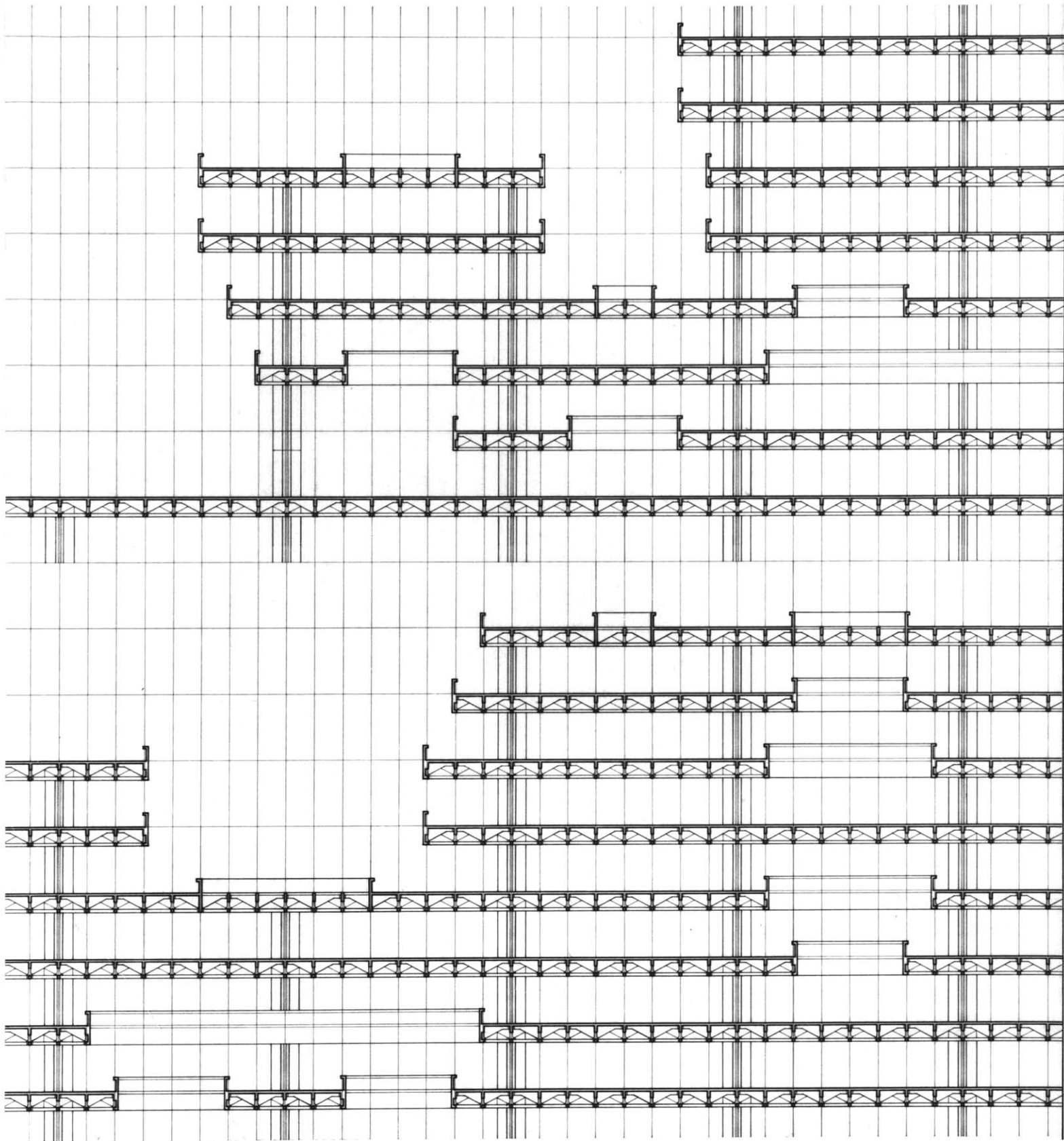


SYSTEM COMPONENTS



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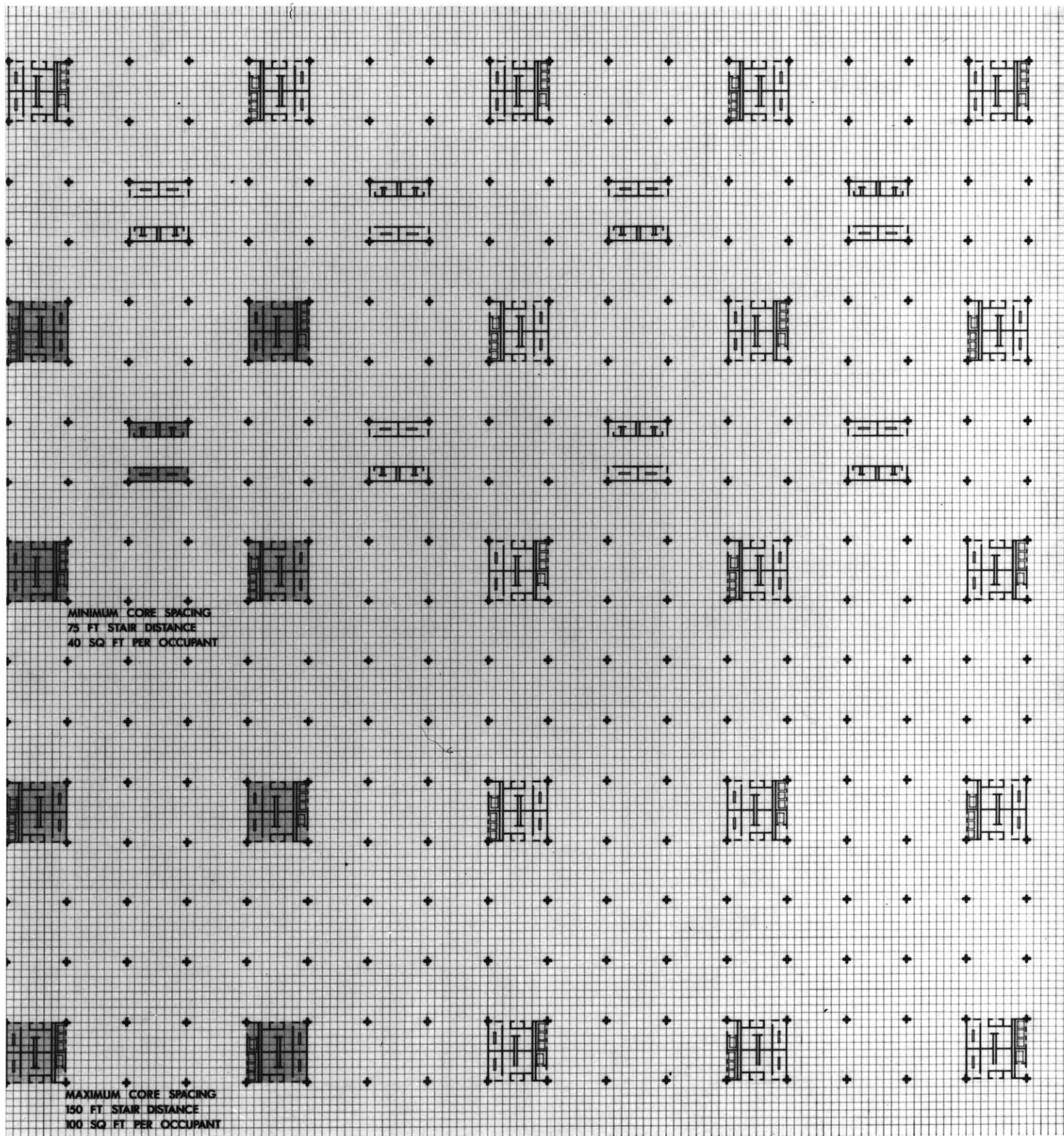


SECTION VARIATIONS

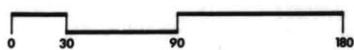


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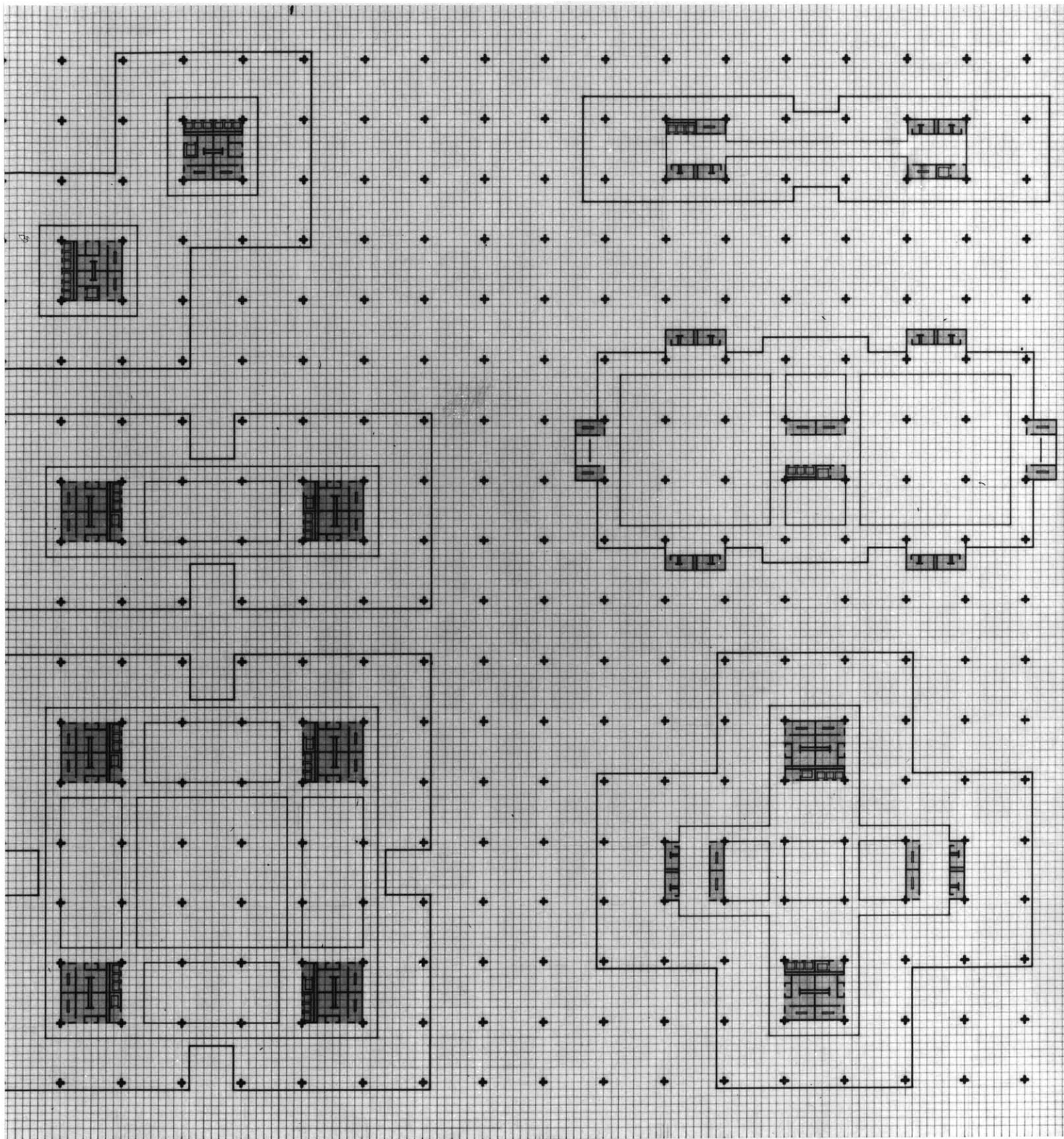


SYSTEM NETWORK

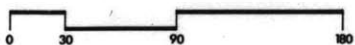


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PLAN VARIATIONS
GROWTH PATTERN



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